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Soils of the Laloanea Farm, Northwestern Upolu, Western Samoa[1]

R. J. MORRISON[2] AND M. ASGHAR[3]

ABSTRACT: Soils of the Laloanea Farm (40 ha), in the uplands of northwestern Upolu, Western Samoa, were studied by an examination of nine pedons composing two toposequences, one running S–N and the other W–E across extensive portions of the farm. Over short distances considerable variability in the soils has led to their classification into two soil orders of Soil Taxonomy (Entisols and Inceptisols), two suborders, three great groups (Troporthents, Humitropepts, and Dystropepts), four subgroups, and seven families. Major factors contributing to the variability were depth to basaltic boulders or flow rock, presence or absence of a cambic horizon, amount of organic carbon in the profile, particle size distribution in the control section, and occurrence in some pedons of andic properties. Soils all had an oxidic mineralogy class and an isohyperthermic soil temperature regime. Relationship of the factors affecting variability to topographic position is discussed, together with an overview of the physical, chemical, and mineralogical properties of the soils. Similar variability might be expected in other humid tropical situations on young basaltic landscapes with steep, rolling, and benched terrain.

WESTERN SAMOA CONSISTS OF four volcanic islands and series of islets lying between 13° and 15° S latitude and 171–173° W longitude. The two main islands, Upolu and Savai'i, are composed of a mass of successive olivine basalt flows, and the landscape is the result of subaerial erosion of two major lava domes. The age of the flows ranges from the Fagaloa flows of the early Pleistocene up to the present century, with the last major event (on Savai'i) occurring in 1905–1907 (Kear and Wood 1959). The climate is humid tropical with rainfall varying from 2000 to 7000 mm annually; some areas have a weak dry season during June–October but there is no true leeward coast. Temperatures at sea level average 26–27°C, with a drop of about 0.65°C for each 100-m rise in altitude (Curry 1955).

Much of the terrain is steep land, and these areas have a thick vegetative cover of primary or secondary forest, or dense scrub. Some agricultural development has occurred in the rolling and flat areas with the production of root crops, copra, cocoa, bananas, and more recently passionfruit and pastures on flat areas of Upolu.

Early studies of soils of Western Samoa were those of Hamilton and Grange (1938), Seelye et al. (1938), and Birrell et al. (1939). The first comprehensive maps were those of Wright (1963), published at scales of 1 : 40,000 (Upolu) and 1 : 100,000 (Upolu and Savai'i). Wright did not discuss the variability within series or mapping units (apart from separation into phases). Schroth (1970) attempted an analysis of the variability of certain characteristics, but examination was confined to a limited number of pedons and did not include an evaluation of variability within the established mapping units.

The Laloanea Farm of the University of the South Pacific is located in an area typical of many in the uplands of northwestern Upolu (see Figure 1). This farm thus represents a suitable resource for future agricultural re-

[1] This work was funded in part by a grant from the University of the South Pacific Research Committee. Manuscript accepted 2 February 1991.
[2] Institute of Natural Resources, University of the South Pacific, P. O. Box 1168, Suva, Fiji.
[3] University of the South Pacific School of Agriculture, Private Bag, Apia, Western Samoa. Present address: Queensland Department of Primary Industries, P.O. Box 201, Biloela, Queensland 4715, Australia.

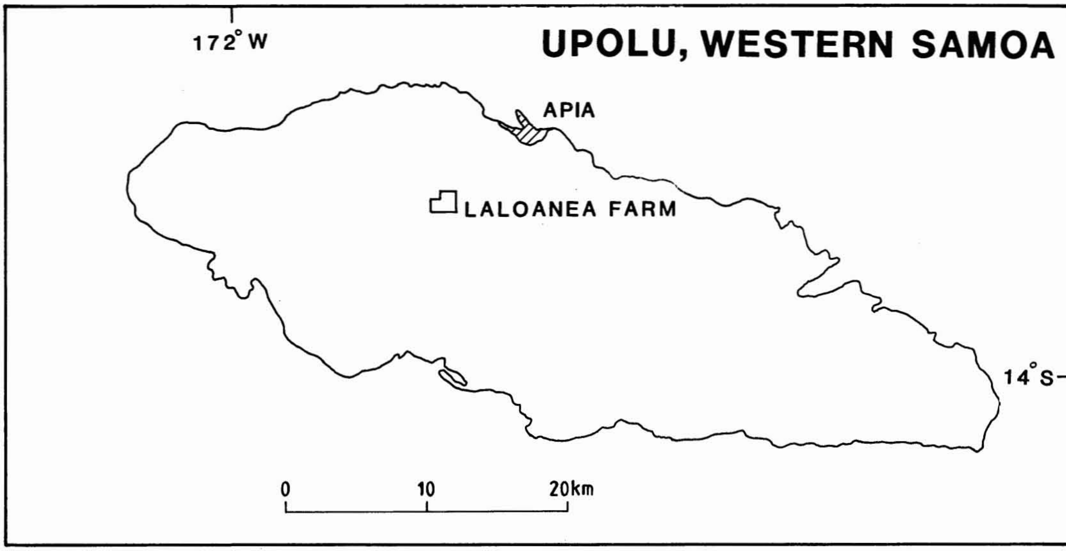

FIGURE 1. Location of Laloanea Farm.

search. Because no detailed soil information was available, a study of the area was undertaken to provide valuable resource baseline data. At the same time, the survey permitted an investigation of the variability of the basalt-derived soils located within the single mapping unit (the Avele stony silty clay and related very stony soil) in the 1 : 40,000 map of Wright (1963), which characterizes the farm site. Data necessary for classification by Soil Taxonomy (Soil Survey Staff 1975, 1990) were obtained so that the Western Samoan soils could be better related to those of other tropical areas, thus assisting the transfer of soil-based agrotechnology.

MATERIALS AND METHODS

A preliminary auger survey was made of the farm area to indicate the general soil pattern and variability and to identify dominant soils. Two toposequences were selected to illustrate the soil pattern and range of variability (see Figures 2, 3, and 4). The S–N sequence covered the major relief units of the farm, and the W–E toposequence, running from the top of a small cone (LNA 1) across a major portion of gently rolling terrain, demonstrated the changes found at the northern end of the study area.

Pits were dug in each of the representative soils, and the profiles were described according to the procedure used by Taylor and Pohlen (1979), except that the term "nut structure" was replaced by subangular blocky structure. Horizon designations were according to the FAO/UNESCO Legend (1974). The soils were sampled and analyzed as described by Blakemore et al. (1981) or the Soil Conservation Service (1972) of the U.S. Department of Agriculture.

Mineralogical studies were made on whole soil samples (<200 mesh) and on the clay (<2 μm) fraction using X-ray diffraction analysis. This analysis was carried out using an X-ray diffractometer system (Philips XRG-3100) employing a long-fine-focus copper tube operated at 40 kV and 40 mA. By use of a "theta compensating" divergence slit, the same sample area was exposed to the X-radiation over the entire angular range of the diffractograms (2–66°, 2θ). The diffractometer employed a wide-optics, curved-graphite monochromator in lieu of a Ni filter. Sample preparation consisted of bulk air-dry powder for the <200 mesh material and of water suspensions that were air-dried on

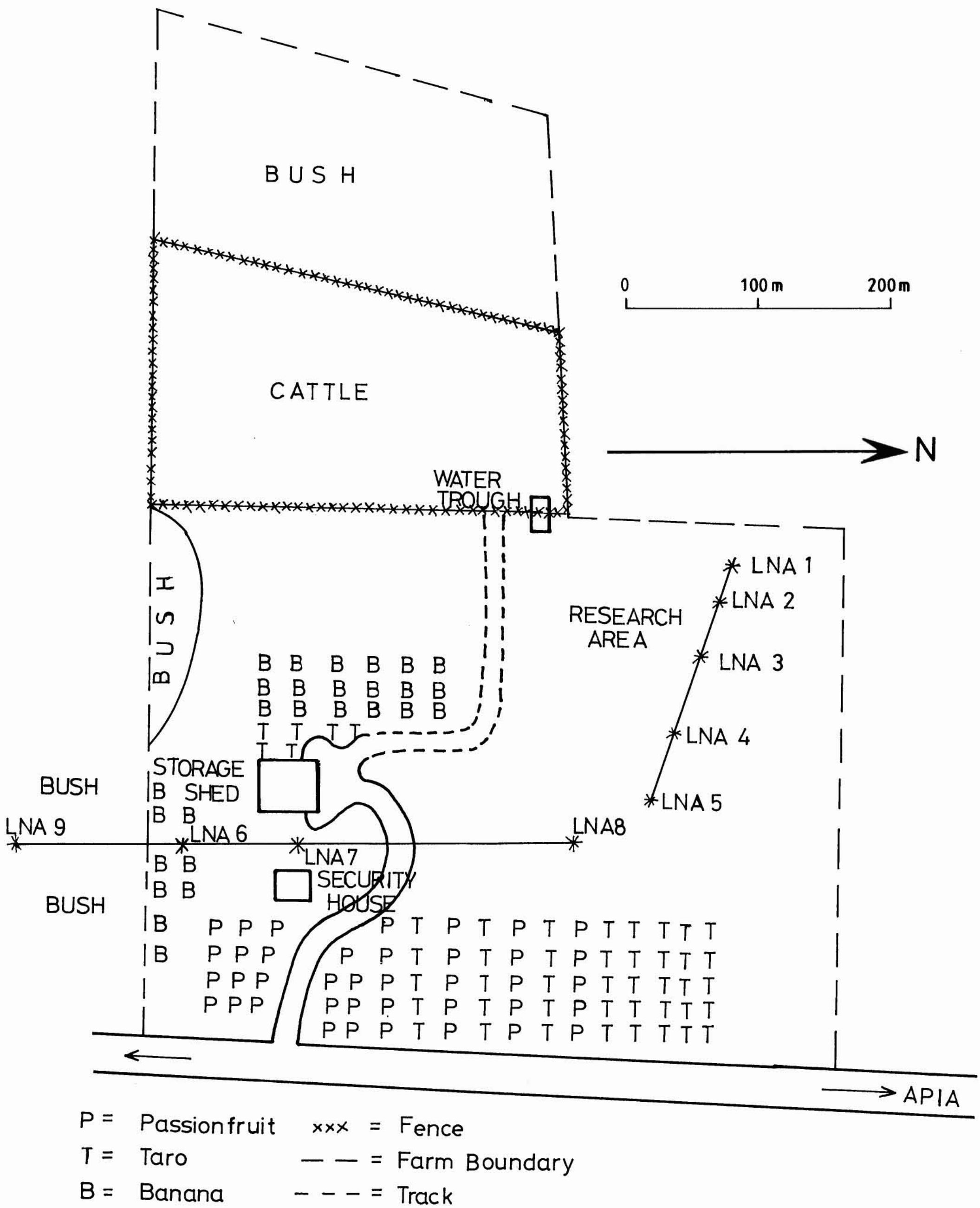

FIGURE 2. Laloanea Farm: land use (1985).

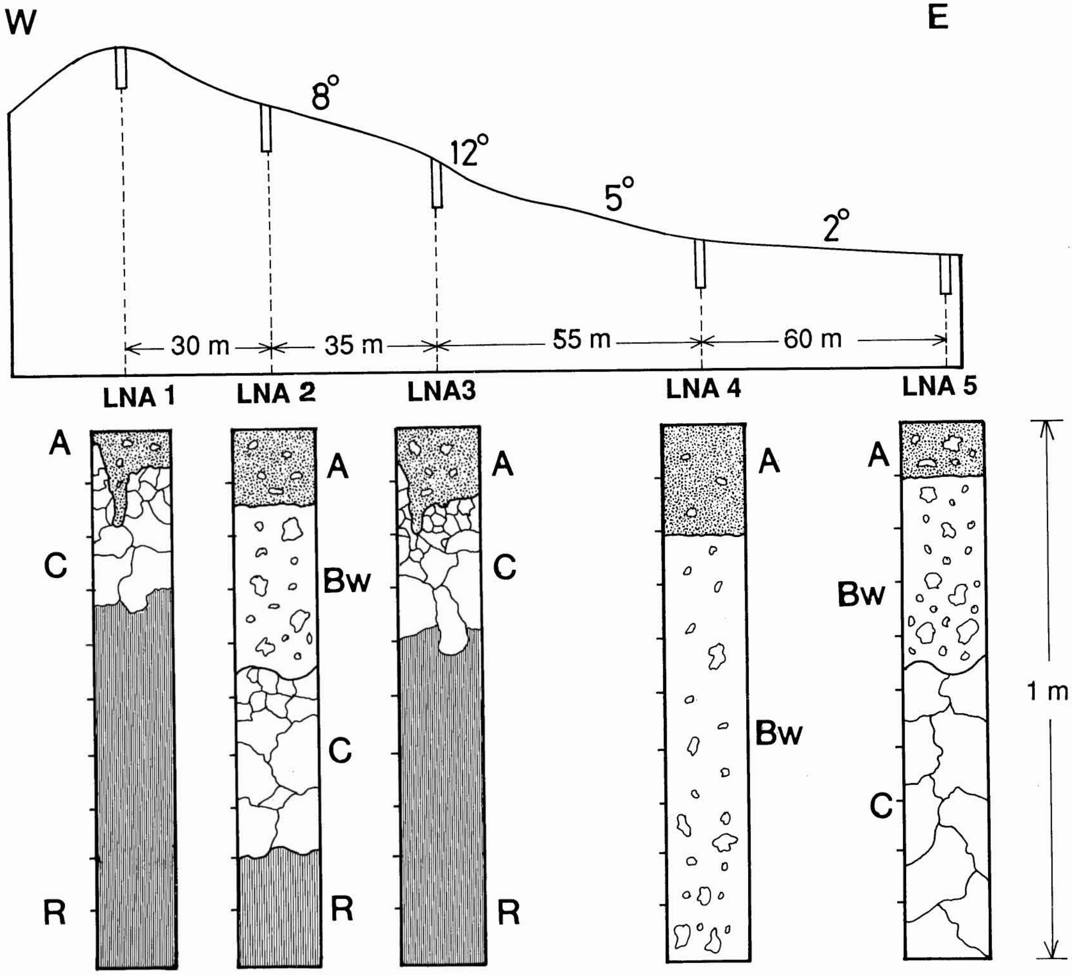

FIGURE 3. Laloanea toposequence no. 1.

molybdenum slides for the clay fractions. Because it is not possible to obtain accurate quantitative soil mineralogical data from X-ray diffractograms alone, the quantitative estimates are in the form of ranges.

The soils were classified according to Soil Taxonomy (Soil Survey Staff 1975, 1990).

RESULTS AND DISCUSSION

The Laloanea Farm soils were formed from Pleistocene or Holocene olivine basalt flow rocks or weathered products derived from them. Because major volcanic events have occurred in the Samoa group as recently as 1907, additions of recent ash must also have taken place. The farm is at 500 m (1650 ft) elevation, so the average annual temperature is estimated at 23°C with a small variation between "winter" and "summer." No rainfall data are available, but annual precipitation has been estimated at 4000 mm, with a very weak dry season June–October (Hydrology Section, Apia Observatory, pers. comm.). The soils therefore have an udic soil moisture regime and an isohyperthermic soil temperature regime. The farm area is generally well drained, and no evidence of sustained imperfect drainage was observed. The present vege-

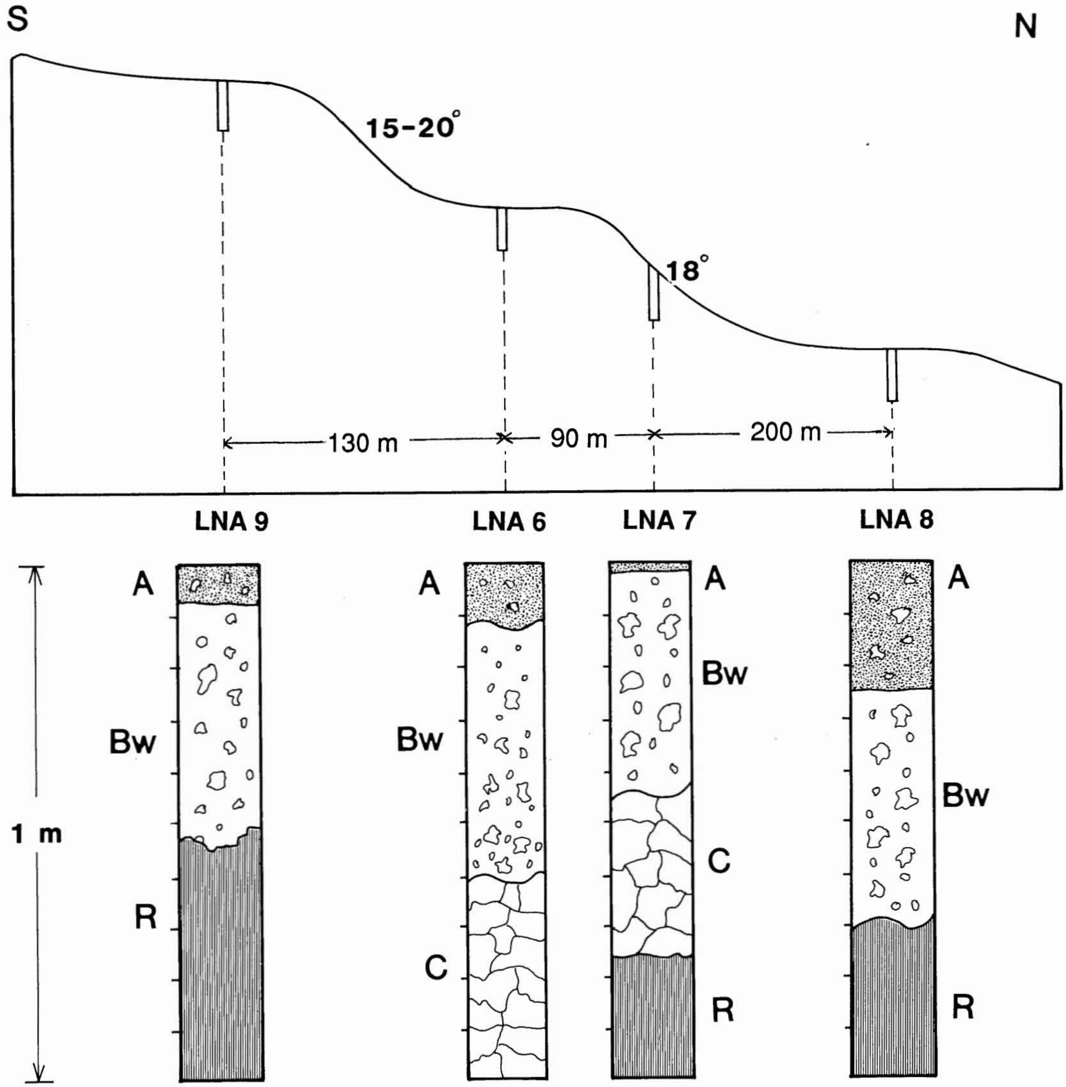

FIGURE 4. Laloanea toposequence no. 2.

tation pattern is shown in Figure 2, while some indication of the relief is given in Figures 3 and 4.

Although the soils in the two toposequences showed some similarities, the soil patterns in the individual sequences were quite different. Profile features and laboratory data are summarized in Tables 1 and 2. Full descriptions and analytical data have been published elsewhere (Morrison et al. 1986).

Toposequence No. 1 (W–E)

Five profiles in this sequence were studied, moving from the summit of a small secondary cone eastward to a relatively flat area close to the bottom of sequence no. 2. The whole area had a dense covering of grass (including *Imperata cylindrica, Paspalum conjugatum,* and *Digiteria* sp.), low shrubs (including *Clidemia* sp.), and creepers (including *Mikania*

TABLE 1

PROFILE FEATURES OF THE LOLOANEA SOILS

PEDON	HORIZON	DEPTH (cm)	LITHIC CONTACT (cm)	STRUCTURE*	FIELD TEXTURE	COARSE FRAGMENTS (% >2 mm)	COLOR (MOIST)
LNA 1	A	0–11 (av)	10–25	med sab + gr	stony silty clay	15	10 YR 3/2–3/3
LNA 2	A	0–14		med sab + gr	stony silty clay	10–15	10 YR 3/2
	Bw	14–95	45–70	med sab + gr	stony silt-loam	15–20	10 YR 3/4
LNA 3	A	0–15 (av)	15–40	med sab	stony silty clay	15–20	10 YR 3/2–3/3
LNA 4	A	0–20		med sab	silty clay	3–7	10 YR 3/2
	Bw	20–125	>125	med/fine sab + gr	clay loam	5–10	10 YR 3/3
LNA 5	A	0–10		med/fine sab + gr	stony silty clay	5–10	10 YR 3/2
	Bw	19–45	40–75	med sab	stony silty clay	10–15	10 YR 3/4
LNA 6	A	0–12		med sab	silty clay	3–7	10 YR 3/3
	Bw	16–60	50–100	med/fine sab	stony clay loam	10–15	10 YR 3/4
LNA 7	A	0–2		med sab	silty clay	n.d.	10 YR 3/3
	Bw	2–45	40–75	med/fine gr	silty clay loam	n.d.	7.5 YR 3/4
LNA 8	A	0–25		med sab	silty loam	5–10	10 YR 3/3
	Bw	25–70	70	med sab + gr	stony loam	10–15	10 YR 3/3–3/4
LNA 9	A	0–7		med sab + gr	clay loam	3–7	10 YR 3/3
	Bw	7–52	50–70	med sab	silty clay	5–10	10 YR 3/4

*Med = medium, sab = subangular blocky, gr = granular.

micrantha). All five profiles had a surface covering of poorly decomposed plant material varying from 5 to 7 cm in thickness. Considerable variation in profile characteristics was noted.

LNA 1, located on top of the cone, consisted of a relatively thin stony silty clay A horizon overlying basalt rocks and boulders, the size of the boulders increasing with depth to a lithic contact. The surface materials met the criteria for andic soil materials (Soil Survey Staff 1990) but were of insufficient depth for the pedon to qualify as an Andisol. This pedon was classified as a Lithic Troporthent.

LNA 2, downslope from LNA 1, had many basalt boulders on the surface, creating significant microrelief features. The profile had an ochric epipedon overlying a cambic horizon, below which basaltic boulders were encountered with soil material filling the interstices. This soil also displayed some andic features and was therefore classified as an Andic Humitropept, clayey over fragmental, oxidic, isohyperthermic.

LNA 3, downslope from LNA 1 and 2, was located at a point where the slope showed a marked increase in gradient for a short segment. This slope increase leads to greater water runoff and hence to a relatively shallow profile. The soil showed many similarities to LNA 1 and was also classified as a Lithic Troporthent, clayey-skeletal, oxidic, isohyperthermic. The surface materials show andic features but, unlike LNA 1, did not meet the criteria for andic soil materials.

LNA 4, downslope from LNA 3, lay effectively at the toeslope of both the W–E and the S–N sequences. This pedon had a deep profile (>125 cm to any rock contact) derived from colluvium from the surrounding hills. Because the surface horizon materials had a low bulk density (0.69 mg/m^3) and had sufficient oxalate extractable aluminum and iron to meet the andic subgroup requirements, this pedon was classified as an Andic Humitropept, clayey, oxidic, isohyperthermic.

LNA 5, lying some 60 m east of LNA 4 along a gentle slope, showed many similarities to LNA 2. This site was obviously not receiving the extensive colluvial additions from the S–N slope seen in profile LNA 4. At the family level this pedon was classified as a Typic Humitropept, clayey over fragmental, oxidic, isohyperthermic.

TABLE 2

SOME PHYSICAL AND CHEMICAL PROPERTIES OF THE LALOANEA SOILS

PEDON	DEPTH (cm)	SAND %	SILT % (fine earth)	CLAY %	MOISTURE RETENTION AGAINST 1500 kPa (%) F. MOIST	AIR DRY	BULK DENSITY mg m^{-3}	pH (H_2O)	C %	CEC (cmol/kg) (pH 7)	Ex Bases (cmol/kg) (pH 7)	P retn %	Al_{OX} %	Fe_{OX} %	Al_{CDB} %	Fe_{CDB} %
LNA 1	0–11	9	29	62	69.5	32.0	0.49	4.9	8.6	51.5	20.1	85	1.98	1.84	2.93	8.45
LNA 2	0–14	21	42	37	49.7	13.0	0.50	4.9	11.1	45.4	13.2	84	0.88	0.92	3.26	9.76
	14–45	18	24	58	42.0	20.1	0.73	5.6	3.3	26.5	26.5	93	1.16	1.09	3.79	10.88
LNA 3	0–5	7	25	68	63.8	41.0	0.59	4.8	8.8	42.0	8.1	73	0.97	1.59	3.24	9.73
LNA 4	0–20	11	31	58	46.2	24.2	0.69	5.8	6.1	34.6	11.3	72	0.83	0.82	4.28	13.08
	20–70	16	38	46	39.8	20.7	0.90	5.5	1.7	14.6	1.2	98	0.58	0.40	4.50	17.44
	70–125	16	44	40	35.9	20.3	n.d.	6.0	1.1	12.8	1.3	n.d.	0.55	0.43	3.93	14.41
LNA 5	0–10	26	25	49	65.4	32.7	0.49	5.2	16.8	54.9	17.5	62	0.54	0.79	3.45	11.33
	10–45	19	38	43	40.6	21.9	0.82	6.0	2.6	23.7	3.3	95	0.54	0.65	4.45	14.06
LNA 6	0–12	26	26	48	50.5	28.7	0.74	6.2	9.0	45.8	23.6	80	0.59	0.43	3.63	12.52
	12–60	19	39	42	38.4	19.9	0.89	5.8	2.5	21.8	2.2	96	0.56	0.39	4.71	13.06
LNA 7	0–2	7	59	34	21.9	17.8	0.96	6.1	3.4	27.0	8.4	83	0.86	0.62	3.37	11.46
	15–35	2	59	39	31.2	19.1	1.01	5.8	1.7	11.7	0.9	95	0.51	0.58	0.04	11.52
LNA 8	0–25	11	47	42	43.6	24.0	0.67	5.7	7.8	35.6	16.6	63	0.46	0.51	3.46	11.59
	25–70	10	57	33	34.1	18.8	1.04	6.1	0.9	12.5	0.9	97	0.37	0.54	4.20	12.62
LNA 9	0–7	31	28	41	46.7	23.6	0.64	5.8	6.8	34.6	7.3	85	0.58	0.90	4.47	12.17
	7–52	11	53	36	39.6	19.0	0.96	5.8	1.9	18.5	0.7	97	0.90	0.71	4.75	13.19

NOTE: F. moist = field moist samples; P retn = phosphate retention; Al_{OX}, Fe_{OX} = acid oxalate extractable aluminum and iron; Al_{CDB}, Fe_{CDB} = citrate-dithionite-bicarbonate extractable aluminum and iron.

Toposequence No. 2 (S–N)

In the S–N transect four profiles were examined, moving across the main topographic features of this foothill area. The soils will be discussed in order on moving from south to north over the sequence.

LNA 9, located in rainforest just outside the southern boundary of the farm, had a dark brown A horizon overlying 45 cm of dark yellowish brown silty clay loam containing some small rounded vesicular basalt boulders. This rested on a vesicular basalt flow rock with up to 1 cm of weathering rind. The pedon is a Dystropept; the organic carbon content was too low (11.3 kg/m^3) to meet the requirements for the Humi- great group and although the top 25 cm showed andic features as described in the 1975 Soil Taxonomy, the 1990 andic criteria were not met and classification at the family level gave a Typic Dystropept, fine, oxidic, isohyperthermic.

LNA 6, located on the next flat bench down from LNA 9, had a dark brown silty clay A horizon overlying about 50 cm of dark yellowish brown stony and bouldery clay loam, with the profile becoming more bouldery with depth. The soil rested on basalt boulders with up to 1 cm of weathering rind and with soil material in the interstices. This pedon had sufficient organic carbon to be a Humitropept and since the andic requirements were not met the family classification was Typic Humitropept, fine, oxidic, isohyperthermic.

LNA 7 was located approximately midslope on a relatively steep (18°) slope below LNA 6. This profile had a shallow (2 cm) dark brown A horizon, overlying a cambic horizon that became more stony and bouldery with depth until it contacted basalt boulders at about 45 cm. Clay loam material was found in the interstices between the boulders. This soil was considered to be typical of the steeply sloping areas between the lava flow benches, particularly where the natural vegetation has been substantially disturbed. Other soils in this slope position had more stones and boulders. This pedon was classified as a Typic Dystropept, fine, oxidic, isohyperthermic.

At the bottom of this sequence pedon LNA 8 was located in a relatively flat area less than 100 m from LNA 5, in a slightly convex section of a concave toeslope. The profile had a slightly stony umbric epipedon overlying a stony and bouldery loam cambic horizon, which in turn rested on basalt flow rock with a weathering rind of less than 1 cm. Organic carbon levels were high and this pedon was therefore classified as a Typic Humitropept, fine-loamy, oxidic, isohyperthermic.

Soil Variability

As stated earlier, the Laloanea farm was included by Wright (1963) on the 1 : 40,000 map of Upolu within a single unit—the Avele series. The Avele series was classified by Wright (1963) as latosolic soils (possibly Humic Latosols) of the foothills, having a very weak dry season, derived from mixed pahoehoe and aa lavas. The colors observed at Laloanea were sometimes more grayish in the topsoils and more yellow in the subsoils than in the two reference pedons described by Wright. Other features that were observed (e.g., texture, structure, depth to rock), however, were compatible with the previous descriptions apart from the very shallow profiles, which were not described in the original report.

The summary of classification in Table 3 shows that within the farm and hence within the mapping unit there were seven soil families, which could be further divided into phases on the basis of slope class. All of the soils had the same mineralogy class (oxidic) and temperature regime (isohyperthermic). The major causes of the variability were the presence or absence of a cambic horizon, the depth to a lithic contact or contact with large boulders, the amount of organic carbon in the profile, the particle size distribution in the control section, and the occurrence in some profiles of andic properties. Several of these factors were interrelated, as discussed below.

Two of the profiles (LNA 1 and 3) had only an ochric epipedon overlying basalt boulders. The other seven profiles had a cambic horizon and are in the Tropept suborder. Separation of the Tropepts at the great group level was made on the basis of organic carbon content

TABLE 3

TAXONOMY OF LALOANEA SOILS

PEDON	FAMILY CLASSIFICATION (Soil Survey Staff 1990)
LNA 1	Lithic Troporthent, clayey-skeletal, oxidic, isohyperthermic
LNA 2	Andic Humitropept, clayey over fragmental, oxidic, isohyperthermic
LNA 3	Lithic Troporthent, clayey-skeletal, oxidic, isohyperthermic
LNA 4	Andic Humitropept, clayey, oxidic, isohyperthermic
LNA 5	Typic Humitropept, clayey over fragmental, oxidic, isohyperthermic
LNA 6	Typic Humitropept, fine, oxidic, isohyperthermic
LNA 7	Typic Dystropept, fine, oxidic, isohyperthermic
LNA 8	Typic Humitropept, fine-loamy, oxidic, isohyperthermic
LNA 9	Typic Dystropept, clayey, oxidic, isohyperthermic

within the profile because all of the soils had low ($<50\%$) base saturation. For the Laloanea soils, organic carbon contents were generally high (see Table 2) and it was therefore surprising that two of the Tropepts did not have sufficient carbon to qualify for inclusion in the Humitropept great group. Pedon LNA 7 had obviously been subject to considerable erosion, while pedon LNA 9 had a relatively shallow lithic contact (52 cm) on basalt flow rock and organic carbon contents that were below average for this area. Pedons LNA 7 and 9 were therefore Dystropepts.

The other five pedons were Humitropepts, three Typic and two Andic. Separation at the subgroup level was based on the presence or absence of andic features. The two Andic Humitropepts (LNA 2 and 4)m were located in the lower part of the farm, and therefore it was considered that the influence of the secondary cone was important in providing a source of younger basaltic material that led to the andic properties. The fact that LNA 1 and LNA 3 also displayed andic features tended to confirm this. The Andic Humitropepts were separated at the family level on the basis of particle size class (one clayey over fragmental, one clayey). The three Typic Humitropepts had different particle size classes, leading to their taxonomic separation at the family level.

Thus, while there are seven different soil families on the Laloanea farm, these can be clearly separated into two groups, the Entisols and the Inceptisols (Tropepts). Within the Tropepts, the soils are separated on the basis of organic carbon content (with depth also having an influence here), the extent of exhibition of andic properties (all the soils show some andic behavior), and the particle size class. Similar variations are found in other areas of Western Samoa, particularly in the uplands, rolling hill country, and foothills, where topography often changes markedly within relatively short distances.

Physics, Chemistry, and Mineralogy of the Laloanea Soils

Most of the soils had material >2 mm in diam., the amounts varying from 4 to 16%. This was exclusive of the large boulders (frequently >50 cm diam.) found at the bottom of several of the profiles. The composition of the coarse fragments also varied considerably, with some topsoils having a few small stones and some profiles having boulders greater than 20 cm diam. Bulk densities were generally low in the topsoils (range 0.5–0.9 Mg/m^3) and moderate (0.7–1.05 Mg/m^3) in subsoils. Apart from the basalt boulders found at shallow depths in some profiles, there are no root limiting layers. Clay contents (laboratory measured) varied from 37 to 68% for topsoils and from 33 to 58% for subsoils. Water retention (against 1500 kPa suction) values showed considerable changes on drying for most samples (often $>20\%$). This was considered as further evidence of the andic properties of many of the samples.

Delta pH or Δ pH ($pH_{KCl}-pH_{H_2O}$) values for topsoils were all negative (-0.4 to -1.1),

TABLE 4

LALOANEA SOILS MINERALOGY (APPROXIMATE COMPOSITION, WHOLE SOIL)

MINERAL	DEPTH (cm)	LNA 1 0–8	LNA 2 14–45	LNA 3 0–15	LNA 4 20–70	LNA 5 10–45	LNA 6 12–60	LNA 7 15–35	LNA 8 25–70	LNA 9 7–52
Amorphous		1?	1?	1?	1?	1?	1?	1?	1?	1?
Halloysite		2	3	2	2	3	3	2	2	3
Gibbsite		4	3	4	4	4	3	4	4	3
Goethite		3	3	3	3	2	3	2	3	3
Maghemite		3	2	2	2	2	2	2	2	2
Ilmenite		3	3	3	3	3	2	2	2	2
Haematite		2	1	1	1	1	1	2	2	1
Augite		1	1	–	–	–	–	–	–	–
Anatase		1	1	1	1	1	1	1	1	1
Magnetite		–	–	–	–	–	–	–	1	–

5 = >50%, 4 = 30–50%, 3 = 15–30%, 2 = 5–15%, 1 = <5%, ? = very difficult to assess.

but for subsoils the values varied around zero (-0.6 to $+0.3$). The soils having zero or positive Δ pH values have associated relatively low cation exchange capacity (CEC) values (see later). Organic carbon contents ranged from 3.4 to 16.9% for topsoils to 0.7 to 3.3% for subsoils, with C : N ratios of 7–11. Phosphorus extracted by the Truog procedure was generally low (2–10 mg/kg), while P retention was high (62–85%) for topsoils and very high (93–99%) for subsoils.

CEC values for topsoils ranged from 27 to 55 cmol/kg, partially reflecting the influence of the high organic matter contents; for subsoils the range was 11–27 cmol/kg, with those soils having zero or positive Δ pH exhibiting the lowest values. None of the Laloanea subsoils had CEC values sufficiently low to be included in Oxic subgroups. In view of the dominant oxidic mineralogy (see below), this may be a consequence of high organic matter contents and the presence of some amorphous materials. Base saturation levels were low for topsoils (20–50%) and very low (4–14%) for subsoils, the base content being dominated by calcium. Exchangeable potassium contents were low (<0.2 cmol/kg) for most soils. The major store of nutrient cations in these soils thus must lie in the surface horizon. Any intensive farming would rapidly reduce the nutrient supply. Similar observations were reported by Wright (1963) and Blakemore (1973). No particular relationship between basic cation concentrations (and base saturation) with position in the landscape was observed.

Citrate-dithionite extractable iron values were often >10% and this is reflected in the fact that all the soils have an oxidic mineralogy class. As shown in Table 4, the soils all contained substantial amounts of gibbsite (20–40%), goethite (10–25%), and maghemite (5–20%) together with ilmenite (5–30%). The presence of maghemite indicates that conditions favorable to its formation must have existed in these soils. Taylor and Schwertmann (1974) summarized these as lower oxidation rates, higher total iron concentrations, higher temperatures, higher pH, and within certain limits the presence of some Fe(III) in the weathering solution. These conditions appear to be met in the uplands of Upolu where the weathering of basalt containing substantial quantities of iron (17% Fe recorded by Seelye et al. 1938) takes place, in a high-rainfall tropical area (i.e., the weathering zone would be kept moist or wet, reducing the rate of oxidation), and where the gradual weathering of silicates keeps the pH around or above 7 (Loughnan 1969).

The available literature (Seelye et al. 1938, Wright 1963, Schroth 1970) suggests that the above data are typical of many soils in the uplands of Upolu. In Tutuila (American Samoa), about 120 km to the east, similar landscape positions are dominated by Mollisols (Nakamura 1984). It is obvious that on Tutuila the basic cation contents are significantly higher than on Upolu, perhaps as a consequence of a more youthful parent material.

Considerable variability within a mapping unit has been demonstrated for some upland soils of Western Samoa. The variability was generally related to physical (depth and particle size) and physicochemical (andic) properties rather than climatic features. Such variability will have a marked influence on research carried out on Laloanea farm and on agricultural production in the hill country of northwestern Upolu. Similar variability will almost certainly be found in other humid tropical island soils formed in rolling and steepland topography from relatively young basalt flow rocks (e.g., in Hawaii, the Cook Islands, French Polynesia, and Fiji).

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